Application of ontology-based engineering and stem approach in learning

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ABSTRACT

Currently, there is a need to improve the educational system and develop interdisciplinary studies at all stages of education, from school to postgraduate education. The implementation of cross-curriculum connections promotes a holistic view of natural phenomena and the relationship between them, that is, this knowledge becomes more meaningful and applicable in practice. The article proposes an approach to building a conceptual model of the content of education in the form of a thesaurus and ontology, the use of which will ensure that the educational information is adaptively selected and put straight. The article discusses the possibility of and experience in using ontological modeling and engineering for the conceptual description of school and higher education. The article discusses the development of the ontological science, technology, engineering, and mathematics (STEM) Education at School model. The article builds an ontological model, which is an integration of the ontology of school and the ontology of university. When filling in the knowledge base, it becomes possible to identify interdisciplinary relationships. The use of ontological engineering methods will improve the quality of education for schoolchildren and students through the semantic description of knowledge of the subject area by using interdisciplinary and STEM approaches in the process of education.

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1. INTRODUCTION

The concept of a market-oriented innovative university is based on the knowledge triangle (education-science-innovation) and aims at large-scale investment in human resources, development of professional skills and scientific research, support to the modernisation of the educational system to meet the needs of a global knowledge-based economy. Knowledge-based education is being replaced by competence-based education, which provides a more complete personally and socially integrated educational outcome. For high-quality training of a specialist, who is ready to work in a dynamically changing economic environment, it is necessary to provide the graduate with not only knowledge but also a competency mix.

It is impossible to master competencies without acquiring activity experience, since they are inextricably linked. The learning process turns into a process of acquiring knowledge, skills, and abilities to obtain meaningful competencies [1]-[3]. An approach to the implementation of the educational process based on competencies is the basic principle of today's educational system. When comparing the educational systems of countries, common principles are needed to assess the results of education. The results are understood as competencies, including the knowledge, skills, and abilities of students.

The aim of the research is to identify cross-curriculum links with ontological modeling and use the science, technology, engineering, and mathematics (STEM) approach in the process of education. Assumption: the use of ontological engineering methods will improve the quality of school children's education due to the semantic description of knowledge about the subject area. Scientific novelty: an ontological model of teaching schoolchildren with the STEM approach, which provides the possibility of promoting schoolchildren's digital skills. The construction of knowledge it is based systems is associated with the development of knowledge representation models and the creation of knowledge bases. There are approaches, models and languages for describing data and knowledge, such as production and formal logical models, semantic networks, and ontologies. Challenges associated with knowledge base formalisation and intelligent information processing method development are tackled through various models and approaches, but ontologies have become increasingly popular [4], [5].

Ontological modeling allows for a conceptual description of a specific subject area, which, in turn, will increase the efficiency of searching and categorising information. Krisnadhi and Hitzler [6], Molinera *et al.* [7] improve the decision-making process with ontologies. Asim *et al.* [8] proposes a sequence of actions for knowledge acquisition from data and ontology element integration. Zulkipli *et al.* [9] provides a systematic review of the literature, which focuses on a comparative analysis of methods for and approaches to ontology construction. Ontological engineering is the process of designing and developing ontologies. Ontological engineering is the process of designing and developing ontologies that combines object-oriented and structural analysis, the key technologies for complex system design. Ontological engineering includes the identification of the main classes of entities, relationships between those classes and feature clusters [10], [11]. Ontological engineering is also studied in foreign works [12]-[15].

The digital economy opens new opportunities for learning. There are new approaches, teaching methods, one of which is the STEM method. The STEM approach is a new global trend. The acronym STEM was proposed in 2001 to denote a trend in the educational and professional fields by scientists from the US National Science Foundation. The term STEM is used to combine academic disciplines, such as STEM. Also, they denote an approach to the educational process, the basis for acquiring knowledge of which is the visualisation of scientific phenomena, which makes it easy to capture and gain knowledge through practice and a deep insight into the processes [16], [17].'STEM education is a modern educational paradox that implies an increase in the quality of students' understanding of disciplines related to natural sciences, technology, engineering, and mathematics. The promotion of STEM competence is designed to improve thinking skills.

In this regard, it is necessary to advance the schoolchildren's digital skills for the subsequent development of educational abilities and personal growth. School students are required to develop in various key academic areas, such as science, mathematics, technology, and engineering, that is, with the new trend of STEM education. Currently, there are professions related to technology at the interface of the natural sciences. The introduction of STEM education from the school curriculum will make it easier for schoolchildren to adapt in further higher education and future professions. An increase in the student's STEM literacy will ensure demand and competitiveness in the labour market [18], [19]. In solving the problems of scientific research, the method of projects and ontological analysis, an object-based approach to software development, optimization methods, and methods of mathematical and computer modeling are used.

In contrast to conventional teaching, STEM teaching changes the form of the educational process. This form is different from our conventional perception of a schoolteacher that we are used to. According to the STEM method, the focus is on a practical task or problem. Students learn to solve the problem practically right away, by experimenting and finding mistakes, rather than solving it theoretically. STEM education provides a number of advantages, such as comprehensive training, the application of knowledge in life, the development of critical thinking, self-confidence, teamwork, interest in technical disciplines, innovation, interdisciplinary training, and technical and technological development. STEM education implies a different teaching approach that shows the convergence of sciences and disciplines in different spheres of life. Ontological knowledge bases have an advantage over traditionally used relational databases. Due to the development of information and communication technologies, it will be necessary to cover the level of semantics, in addition to the level of storage and structures. The use of domain ontology appears relevant and effective for the representation of semantics. Ontologies contain the following conceptual structures: class hierarchies in object-oriented programming, conceptual maps, and semantic networks. The visual approach of ontological engineering is the most popular one. The visual approach combines such basic types of technologies as object-oriented and structural analysis. When building an ontology, it is necessary to determine the basis for describing the main objects, attributes, and classes. For example, "classes, relationships, functions, axioms, and instances" or a multitude of "objects, relationships, roles, and attributes".

The main teaching method used to integrate STEM into the educational space is the method of projects or the project method. The STEM approach allows you to combine mathematics and natural sciences, fine arts and technology, computer science, and physics in project work. This, in its turn, allows students to fully explore the world around them. Today, STEM projects allow you to study the topics and directions of a discipline at the applied and fundamental levels. The project method is not new to the teaching process. This method ensures the interaction between theory and practice of STEM education in the role of an assistant. This method focuses on the student's cognitive work aimed at achieving goals and solving problems. Interdisciplinary projects are performed outside of classroom studies under the guidance of specialists in various fields of education. Depending on the nature of communication, projects are classified as in-class, in-school, regional, and international projects. Integrated lessons are being introduced in the Republic of Kazakhstan, to implement STEM education and meet new trends in education.

Currently, interdisciplinary projects are carried out outside the classroom under the guidance of specialists in various fields of education. The article discusses the need to introduce integrated and interdisciplinary lessons into educational programs at all levels of education, from school to postgraduate education. This is currently a problem. An approach is proposed, using ontological engineering and STEM education to educational programs, which will make it possible to identify interdisciplinary connections at school, and further improve and apply them when studying at a university. The use of ontological engineering methods will improve the quality of teaching schoolchildren and students due to the semantic description of the knowledge of the subject area through the use of an interdisciplinary concept in the educational process. Thus, educational organizations and universities will be able to respond flexibly to changing environmental conditions and develop educational programs, improving their quality and demand in the market of educational services.

2. METHOD

Research methods are based on knowledge management, ontological engineering, service-oriented programming methods, description logic and logical knowledge acquisition methods. Also, they are based on the theory of sets and graphs, the syntactic parsing theory, and the ontology creation concept. The core objectives of ontological engineering are to enhance the level of integration of information necessary for making managerial decisions; improve the efficiency of information retrieval; make sure knowledge can be jointly processed on the basis of a single semantic description of the knowledge space. When building an information system, the ontological model is an easily expandable and customisable knowledge system. The research chose an ontological approach to building a unified educational space, which will take into account the labour market requirements at the national and international levels. The most developed ontology representation language is currently web ontology language (OWL), which extends the capabilities of xtensible markup language (XML), resource description framework (RDF) and RDF Schema [20]-[22].

Ontology development method can be defined as an algorithm of actions to be performed when building ontologies to ensure the clarity, consistency, extensibility, reusability, and reliability of the ontology [21]. Unfortunately, there is no standard agreed method for constructing an ontology [22]. There is no one-size-fits-all approach to the development of ontologies. Instead, the idea of combining methodologies and methods is supported by practitioners in the field of ontologies [23]. However, the general steps of the ontology construction method proposed in [24], as shown in Figure 1, can be used as a guide for ontology construction. These phases include ontology specification, ontology conceptualisation, ontology implementation, ontology verification and evaluation. At the ontology specification stage, it is necessary to determine the purpose of building an ontology and developing a system, service, and ontology application objects, and it is also necessary to describe the subject area and area of interest [24]-[28].

In addition, data collection also takes place at this stage. Then, at the stage of ontology conceptualisation, the conceptual model of the subject area is defined, the ontology structure is identified, and ontological relations are compared. Once this is done, the ontology is built at the implementation stage with the necessary implementation tool. After building an ontology, it should be checked and evaluated by either involving experts in the subject area or quantifying the accuracy and completeness of the ontology [9]. Improving the quality of teaching schoolchildren can be achieved through the semantic description of knowledge about the subject area using methods of ontological engineering. The method of ontological engineering implies building a three-tier model of the field under study: top-tier ontologies, domain-specific ontology, and applied ontologies [29], [30]. The sequence of actions for developing an ontology. First, it is needed to perform an analysis of the subject area, make a synthesis of concepts and relationships, then select objects, attributes, relationships, and processes. This sequence is shown in Figure 1.

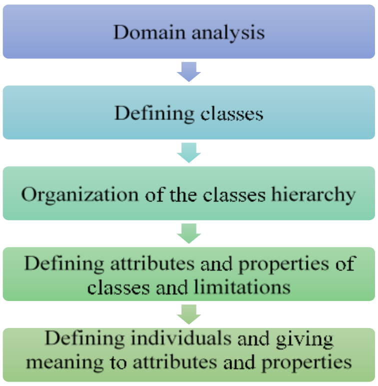

Figure 1. Stages of ontology development

Creating and using a knowledge base. Ontologies allow us to build domain models by combining declarative characteristics and definitions. Experts in the field of application set the following basic requirements for the means of creating ontologies Figure 2.

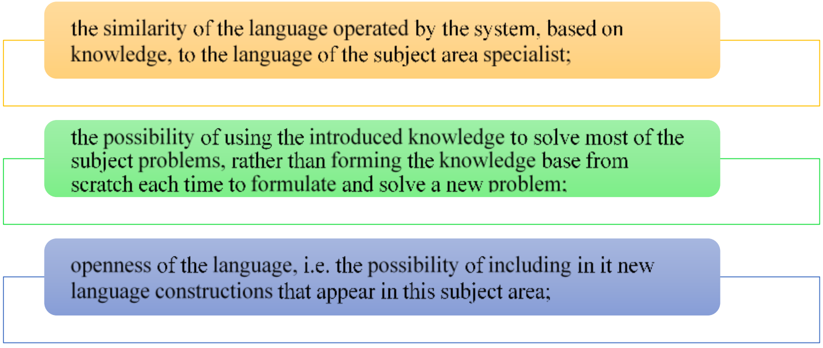

Figure 2. The main requirements of experts

Using the presented sequence of actions, we perform the construction of ontologies. Improving the quality of teaching schoolchildren can be achieved through the semantic description of knowledge about the subject area using methods of ontological engineering. Created classes that describe the subject. Based on the structure of the subject, an ontological model is built in the Protégé editor. Further, it can be exported to XML or another format. Based on the conducted ontological engineering, an ontology of the curriculum content for schoolchildren was built. This ontology includes the following classes:

- Course
- Subject
- Learning achievements (subclasses: skills, abilities, knowledge, and competencies)
- E-learning tools (subclasses: databases, technical means, information technologies, and information systems)
- Participants in educational relations (subclasses: management, student, and teacher)
- Regulatory framework (subclasses: standards, regulatory documents of education, and laws of the republic of Kazakhstan)

Combining the ontology built with a specific subject by completing the model with specific data corresponding to the training course will allow you to get a full-fledged knowledge database with which you can perform various actions, forming various representations of educational materials in various formats at the output. This approach will improve the effectiveness of the development of educational courses and the use of educational content. In the future, this ontology will be supplemented and integrated with existing ontologies, such as university ontology. Improving the quality of teaching schoolchildren can be achieved through the semantic description of knowledge about the subject area using methods of ontological engineering. The ontological model of the distributed knowledge database of the university was developed using the Protégé resource. When using the Protégé resource the administrator is provided with the following features: i) editing hierarchy of classes; ii) editing object properties and data type properties; and iii) creating and editing individuals.

Created classes that describe the subject. Based on the structure of the subject, an ontological model was built in the Protégé editor. Computer science as a school subject allows students to form digital skills. It is necessary to develop these digital skills and reach new levels. Therefore, it requires the formation of computational and algorithmic thinking in schoolchildren. One of the steps in this direction is the modernization of the education system, and the introduction of new directions in the field of information technology in school curricula. In recent years, much attention has been paid to computer-aided learning, robotics, and ontological engineering. It is widely acknowledged that the future of information technology lies behind these trends. Computer-aided learning is a popular field of knowledge. Computer-aided education begins in high school. Python allows you to study computer-aided learning, bypassing the in-depth mathematics studying. Computer-aided learning is one of the most promising areas in the development of information technology. Computer-aided learning methods are used in various fields of human activities. In this regard, it is necessary to study this area starting from the school course in computer science. Further, graduates can develop their skills and improve their knowledge at university or in various training courses. Let's study an example of the implementation of the STEM approach. The interaction of STEM elements for "computer-aided learning" is shown in Figure 3.

Educational robotics allows you to develop programming and project design skills. It works as an integrator of all STEM elements. Moreover, it is possible to calculate the motion speed of a Lego typewriter and the distance traveled by it in the framework of an optional school course on the basics of robotics. This can be done using the terms "arithmetic operations" in Mathematics and "cycle" in computer science. This process teaches the student the principle of calculating the total speed of cars, and the distance traveled. Thus, STEM education allows students to develop project thinking by linking their knowledge with environmental processes. An example of the implementation of the STEM approach, the interaction of STEM elements for "robotics" is shown in Figure 4.

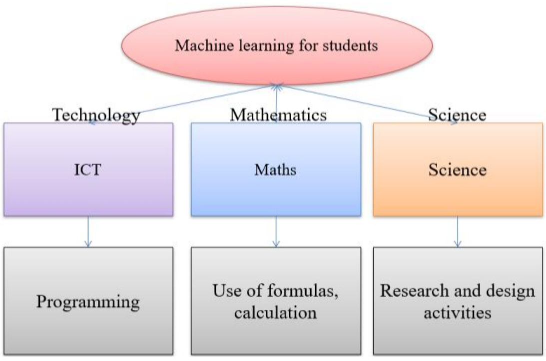

Figure 3. Computer-aided learning for schoolchildren

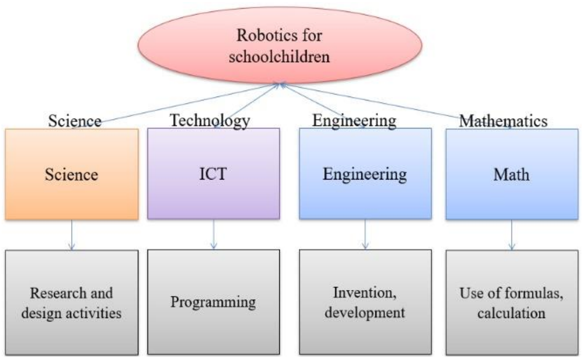

Figure 4. Robotics for schoolchildren

Robotics allows students to develop fundamentally new skills: critical thinking, creative problem solving, group work, creativity, adaptation, coding, communication skills, responsibility, and systematization. The STEM approach is actively used in teaching computer science. Thus, there are many topiallowsd sections in computer science that allow you to interact with STEM elements.

3. RESULTS OF A COMPUTER EXPERIMENT

The building of an ontology begins with the creation of an ontological domain model. To do this, you need to define the base classes and the relations between them. It is required since we are developing a school ontology that allows us to show the interaction of STEM elements for computer science as a subject. As an example, let's analyse the building of the ontology of the "robotics" and "computer-aided learning" sections. We will be using these ones as they clearly show the interaction between STEM elements. Robotics is directly related to STEM education. Robotics combines design, technical creativity, and programming. Robotics training begins with forming an understanding of engineering and programming among schoolchildren. Let's apply the ontological approach and STEM approach to the school disciplines mastery, using the example of the "robotics" discipline. A fragment of the entered data from the computer science electronic textbook.

Classes, textbook paragraphs, and their relations are shown. A fragment of the built ontology reflecting inter-subject connections is shown in Figure 5.

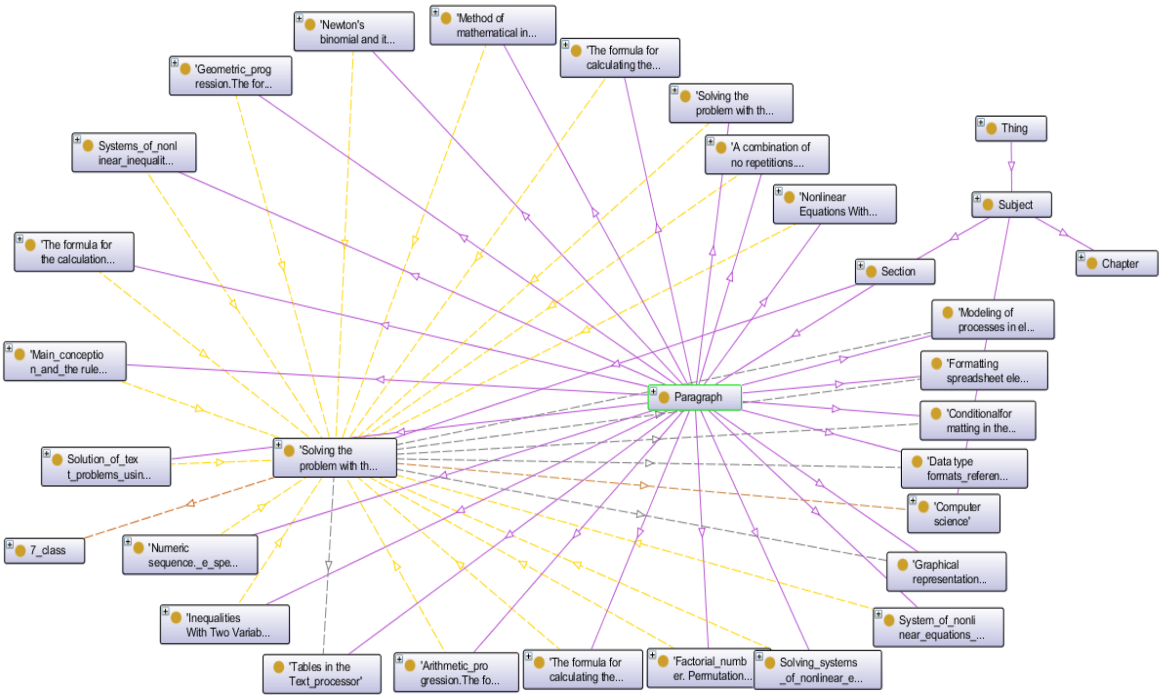

Figure 5. A fragment of the built ontology

Created a property of objects reflecting inter-subject relations: has inter subject communication. Using the tab, executed the command tools-usage for the has inter subject communication object property, you can see all the mathematics and computer science inter-subject relations in ontology", is shown in Figure 6. For example:

- 'A combination of no repetitions. Basic combinatorics formulas' subclassof hasintersubjectcommunication some 'solving the problem with the help of electronic tables.
- 'Arithmetic_progression. The formula of the nth term of the arithmetic regression' subclassof hasintersubjectcommunication some "solving the problem with the help of electronic tables.
- 'Factorial_number. Permutations and placements' subclassof hasintersubjectcommunication some 'solving the problem with the help of electronic tables.
- 'Geometric_progression. Tform of the nth member of the geometric progression' subclassof hasintersubjectcommunication some 'solving the problem with the help of electronic tables.
- 'Inequalities with two variables' subclassof hasintersubjectcommunication some 'solving the problem with the help of electronic tables".
- 'Main_conception_and_the rule of combinatory_ (rule of summation_reduction_reduction)' subclassof hasintersubjectcommunication some 'solving the problem with the help of electronic tables".
- ''Method of mathematical induction' subclassof hasintersubjectcommunication some 'solving the problem with the help of electronic tables.
- 'Newton's binomial and its properties' subclassof hasintersubjectcommunication some 'solving the problem with the help of electronic tables'.
- 'Nonlinear equations with two variables' subclass of hasintersubjectcommunication some 'solving the problem with the help of electronic tables.
- 'Numeric sequence. _e_species, _proposals_ad_properties' subclassof hasintersubjectcommunication some 'solving the problem with the help of electronic tables.

Deduced a small fragment of an ontology with interdisciplinary relations between mathematics and computer science. The arithmetic progression included in chapter 3 of the algebra electronic textbook grade 9 can be solved based on the material provided in the computer science textbook for the 7th grade "solving problems using electronic spreadsheets", is shown in Figure 7.

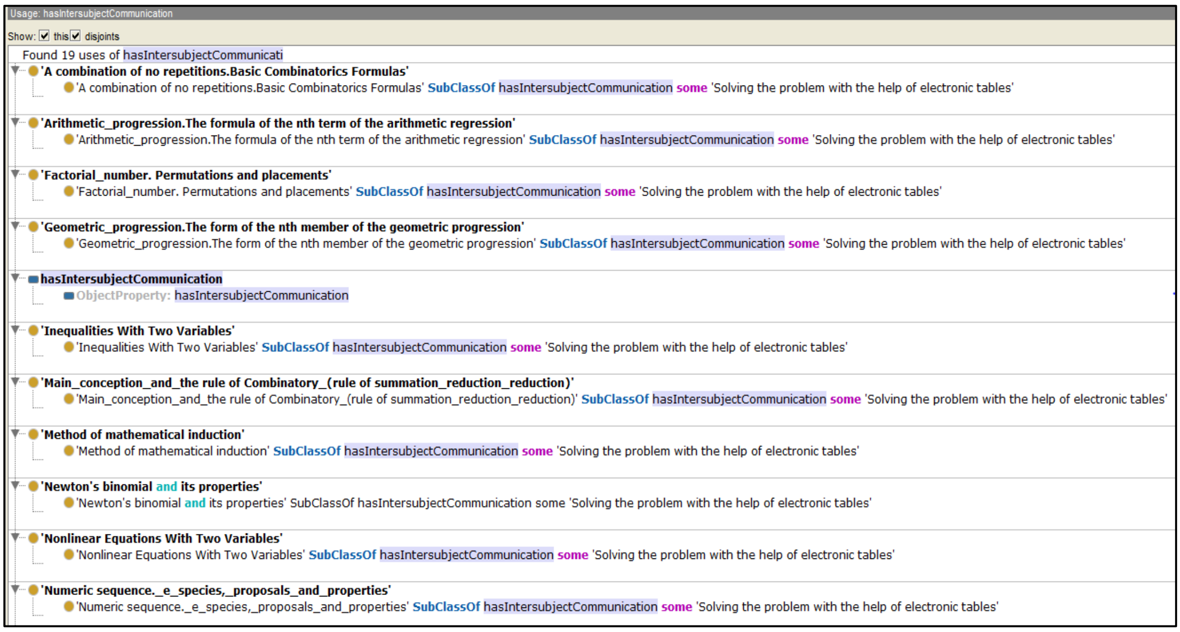

Figure 6. The tools-usage command

The building of an ontology begins with the creation of an ontological domain model. To do this, you need to define the base classes and the relations between them. It is required since we are developing a school ontology that allows us to show the interaction of STEM elements for computer science as a subject. As an example, analysed the building of the ontology of the "robotics" and "computer-aided learning" sections. We will be using these ones as they clearly show the interaction between STEM elements. Robotics is directly related to STEM education. Robotics combines design, technical creativity, and programming. Robotics training begins with forming an understanding of engineering and programming among schoolchildren. Applied the ontological approach and STEM approach to the school disciplines mastery, using the example of the "robotics" discipline. The processing subsystem of the ontological knowledge base of the university "STEM disciplines" ontoSchollSTEM.owl, is shown in Figure 8.

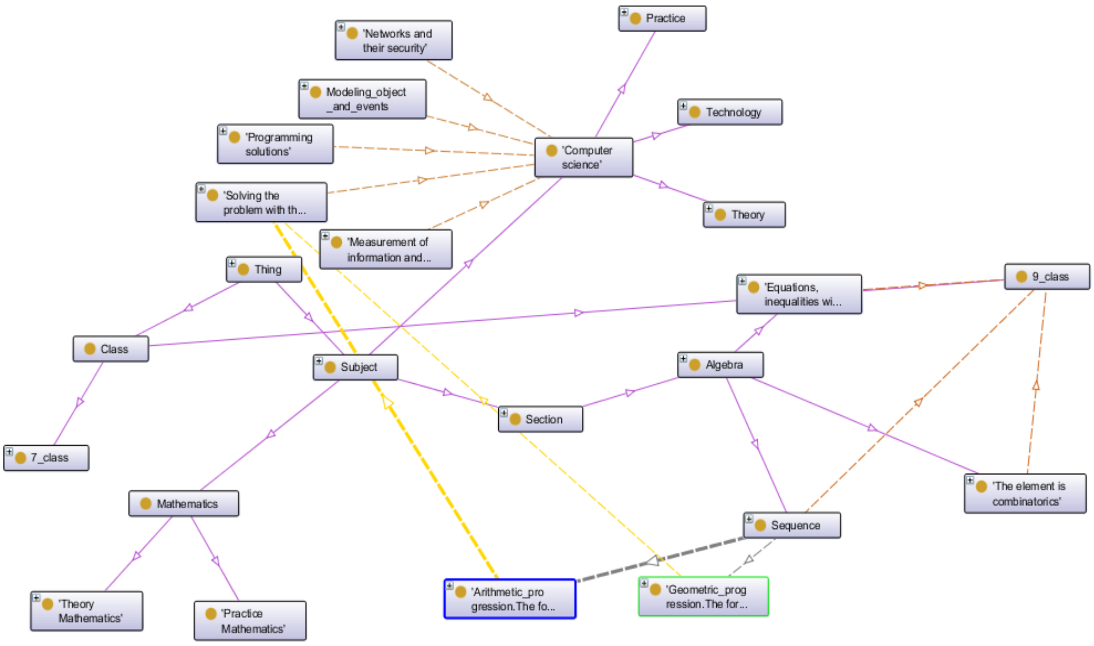

Figure 7. Fragment of the constructed ontology for inter-subject relations between mathematics and computer science

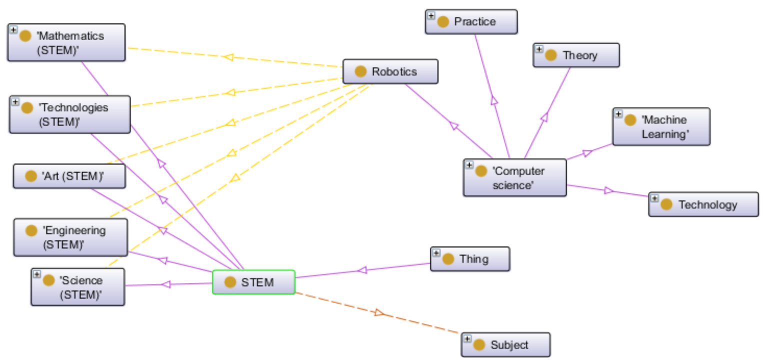

Figure 8. A fragment of the classes' hierarchy

A lesson plan or a short-term plan for a teacher of a secondary education organization consists of the following basic elements: section; teacher's full name; date; grade; lesson topic; teaching objectives in accordance with the curriculum; lesson objectives; lesson phase/time; teachers' actions; student's actions; evaluation; and resources. The STEM education at school ontology was built, which includes the structure of the school educational process, STEM elements, and lesson plan", is shown in Figure 9. The "STEM education at school" ontology is a knowledge base for storing knowledge and school data that are interconnected by certain rules and interrelations.

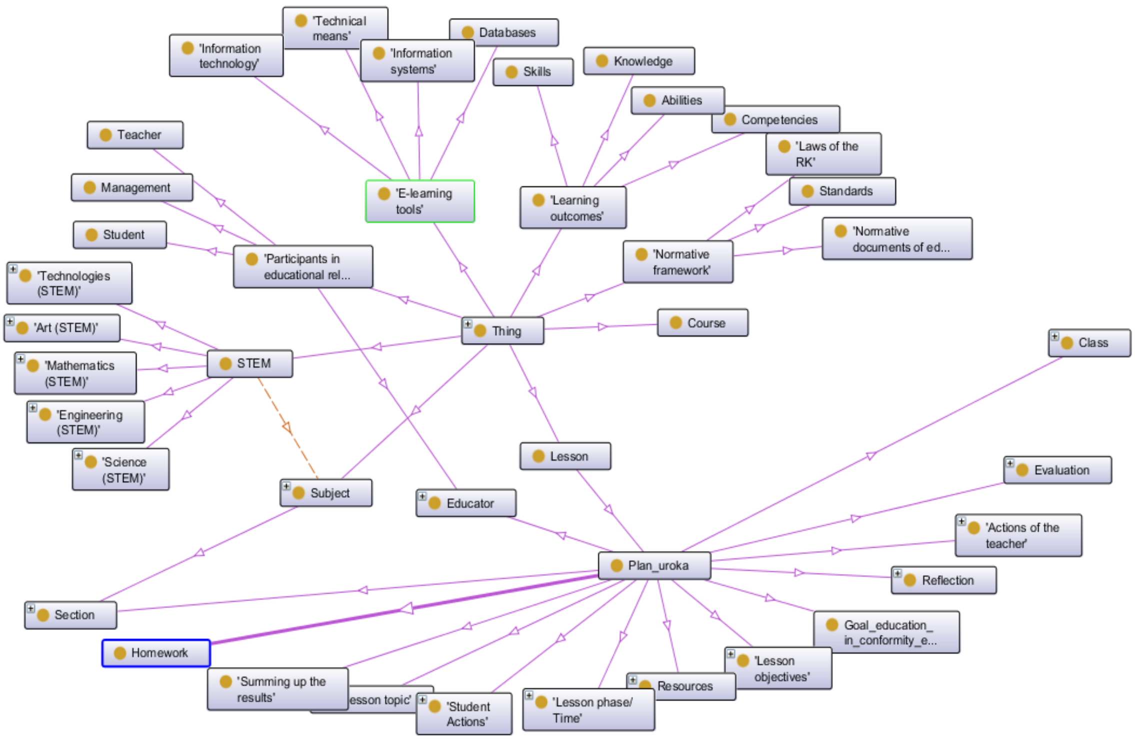

Figure 9. "STEM education at school" ontology

4. CONCLUSION

It is possible to identify interdisciplinary relations between mathematics and computer science with the help of the built ontological model and by replenishing the school's knowledge database. You can continue to make the necessary changes to this knowledge base and thereby update the school's data. This approach will make it possible to identify interdisciplinary links at school, and further improve and apply them when studying at a university. When filling in the knowledge base, it becomes possible to identify cross-curriculum relationships. The application of ontological engineering methods will improve the quality of education of schoolchildren and students through the semantic description of knowledge of the subject area by using the inter-subject concept in the educational process. The "STEM education at school" ontological model has been developed. The ontology "STEM education at school" was built using the Protégé 4 editor. It contains the necessary classes, relations, properties, and individuals of the school educational process. Requests for this ontology have been fulfilled. The hierarchy of classes and fragments of the constructed ontology was presented. This approach will improve the efficiency of the development of lesson plans, using the STEM approach and the use of educational content. The introduction of STEM education to the school curriculum will make it easier for students to adapt to further higher education and obtain a future profession. Increasing the student's STEM literacy will ensure demand and competitiveness in the labor market. STEM is not just a combination of different disciplines in one project, it is an attempt to develop a synergistic effect from perceiving the laws of the universe. Some researchers see STEM as a separate philosophy of understanding the laws of the universe through the prism of certain objects, while others see it as a way to prevent science from being separated from the real world. In this regard, when implementing STEM technologies, it can be difficult to prioritise the disciplines involved in a particular project and take into account all the tasks set. Impulses of this educational technology, such as a phenomenon, context, research, project, problem, can confuse students in achieving their goals. In analysing the experience of countries working with STEM, we can conclude that this technology is very interesting and useful in terms of promoting future 4K (creativity, teamwork, critical thinking, and communication) skills that students need today. At the same time, when introducing this technology, it is essential to keep in mind the goals of education and the importance of each subject in teaching students. The ontological model "STEM Education at School" is built in the article by a manual method; in the future, the knowledge base of anthologies is supposed to be filled with a semi-automatic method.

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